Principles of Remote Exploration (PREP) for Mars Mars Rover Sample Analysis Mission

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Abstract

Principles of Remote Exploration (PREP) for Mars is a framework for teaching basic concepts that can be applied to the design and implementation of a remotely operated experiment. *PREP for Mars* provides an opportunity for every student to play the role of a NASA scientist or engineer and participate in the design and deployment of a remotely operated mission. The *PREP* framework explicitly addresses middle school education standards in mathematics, technology and science; however, bridges are provided for interdisciplinary activities in reading, history and art. The framework is designed to be implemented with varying degrees of technology insertion to accommodate the range of technology available in schools. *PREP for Mars* is an ideal preface for activities in the design and development of robotic experiments and could be used as an introduction to the fundamentals prior to participation in engineering activities such as FIRST Robotics and BotBall.

Background

NASA engages in planetary exploration and is preparing to send two rover missions Mars this year. Launch is planned for May/July 2003, with landing on Mars anticipated in January 2004. Students can engage in learning activities relating to the exploration of Mars and the deployment of remotely operated rovers. NASA provides educational materials covering a range of topics and grade levels (See section on **Web Extensions**).

The exercise described here, *Principles of Remote Exploration (PREP) for Mars*, engages students in the development and deployment of a mock remotely operated Mars Sample Analysis Mission. Content areas that can be related to the Mars rovers range span science, mathematics and technology. Topics include, for example, Solar System studies (e.g. was there ever life on Mars and what are the implications for life on Earth?), and planetary geology (e.g. comparison of geology of Earth and Mars, in particular weathering effects and internal planetary evolution processes such as volcanism). Skills required for the activity include measurement, graphing, and mapping. The activity offers numerous opportunities to address process standards, such as problem-solving, understanding technology and its use, and the ability and understanding to undertake scientific inquiry. *PREP for Mars* offers opportunities to teach the principles and concepts in mathematics and science outlined in the National Standards in a hands-on, problem-solving way. Collaboration among students is strengthened as the teams work toward their goal of completing the mock Sample Return Mission. Cross disciplinary activities in reading, history and art are also possible (See section on **Bridges**).

An important contribution of this exercise to the education landscape is that it is an engaging mechanism to create meaningful learning opportunities to promote student understanding and achievement. *PREP for Mars* offers a foundation experience grounded in mathematics and science concepts that a teacher can illuminate with concrete examples.

The Activity: PREP for Mars

The goal of this activity is to deploy a remotely operated rover to retrieve a sample of the remote terrain. We chose Mars as the context for this activity. This activity can be implemented as a competition among teams; no more than five students per team is recommended.

Student Teams

The teams should be divided into four components: the rover (ROV), mapping (MAP), communication (COM) and calibration (CAL). Each component should comprise up to two students, except the rover: that is one student (we have also used parents, teachers and student aides as rovers). We recommend that the Communications Team comprise two students; this increases efficiency of delivering the commands to the rover on *Mars*. These students in the various teams shall be referred to hence as MAP, COM, and CAL. MAP produce scale maps of the terrain using graph paper, first *Arizona* and then *Mars*. COM develop the communications strategy and deliver the commands to the rover. CAL monitor the rover's progress, reporting to MAP to update the rover's position on the map. All students work together to plot the rover's course on the map, and all except the rover work together to determine which commands to send to the rover. The students should choose their roles prior to the start of the *Arizona* phase. It should be clear to the rover that s/he will be blindfolded. For fun, it is recommended that the teams name their rover.

Arizona: Calibration of the Rover (50 minutes)

Before NASA scientists and engineers deploy a rover or any kind of scientific sensor, they must calibrate the responses of the equipment. Before a spacecraft or a rover is sent to a remote location, the terrain must be mapped using remote sensing. In the case of NASA rovers, the final testing phases are often carried out in the dessert, to mimic the conditions on Mars. This *Arizona* phase has four objectives: mapping, communication, calibration, and testing. The first three activities should happen concurrently; the fourth is a culmination of the knowledge gained in the first three.

1. Map the *Arizona* terrain (Mapping Team)

MAP maps the *Arizona* terrain to scale using graph paper. The fiducial marks on the floor or walls will enable the students to calibrate their maps. The students should be told to what actual distance the fiducials correspond. The teacher should show the students the “landing site” and the “sample site” in the *Arizona* terrain. The students should include these locations on their map.

Instructional objective:

- Produce a scale map of an environment. The units, techniques, and spatial relations involved are concrete applications of concepts governed by Measurement.

NCTM Mathematics Standards (6 – 8 Targets)

Measurement

12. Understand measurable attributes of objects and the units, systems, and processes of measurement

c. Understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume.

13. Apply appropriate techniques, tools and formulas to determine measurements

b. Select and apply techniques and tools to accurately find length, area, value and angle measures to appropriate levels of precision

e. Solve problems involving scale factors, using ratio and proportion

Relevance:

NASA uses maps extensively for Earth and space science. All landing sites are mapped to the best of NASA’s ability prior to arrival of the landers. Much of NASA’s imagery is eventually turned into maps of the environment.

2. Develop a communications strategy (Communications Team and Rover).

COM must determine how many commands the rover can reliably execute in each command sequence. COM should keep a log indicating which commands they give to the rover each time, to keep track of what the rover can remember.

The command sequence is delivered as follows:

a. COM touches rovers shoulder
b. COM: `HELLO` <rover name>
c. R: `HELLO`
d. COM reads the command sequence
e. R repeats the sequence
f. steps d & e are repeated until the rover gets it right
g. COM: `CORRECT` <rover name>. `GOODBYE`.
h. R: GOODBYE

The command-response pattern is important to be sure the robot understands the command. The greetings at the beginning and the end of the sequence serve to tell the rover when to start listening and when to stop (recall, the rover is blindfolded). COM repeat this many times to acclimate the rover and to determine how many commands the rover can actually remember. Three to five commands seems to be a reasonable number. Remember: if the rover makes a mistake, it must shut down, and this costs valuable time.

Instructional objective:

- Organize, interpret, and use relevant information to devise an effective strategy for communicating with the rover. This activity simulates the two-way communication between ground-based scientists & engineers and the remotely operated rover.

ITEA Standards for Technological Literacy

2: Students will develop an understanding of the core concepts of technology.

M. Technological systems include input, process, output and, at times, feedback.

Relevance:

Developing a communications strategy is part of every NASA mission, from both a logical and technical perspective.

3. Calibrate the movements of the rover in response to the commands (Calibration Team, Communications Team and Rover).

After COM give a set of commands, the rover executes the commands. At this time, CAL measures the actual performance of the robot. CAL should keep a log of their measurements. For example, how much distance does the rover cover when s/he executes each `FORWARD 3` command? How long does it take the rover to execute each command sequence? The students should do tests on various scenarios: for example, place several objects between the rover and a goal. Is it faster to navigate through the objects, or go around the outside?

Instructional objective:

- Discover and describe a mathematical relationship between the commands given to the rover and the response of the rover through measurement of time and distance.

NCTM Mathematics Standards (6 – 8 Targets)

Algebra

5. Represent and analyze mathematical solutions and structures using algebraic symbols

b. Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope

6. Use mathematical models to represent and understand quantitative relationships

a. Model and solve contextualized problems using various representations, such as graphs, tables and equations

7. Analyze change in various contexts

a. Use graphs to analyze the nature of changes in quantities in linear relationships

Measurement

12. Apply appropriate techniques, tools and formulas to determine measurements

b. Select and apply techniques and tools to accurately find length, area, value and angle measures to appropriate levels of precision

Relevance:

Every scientific instrument must be calibrated so that scientists can relate the output of the instrument to the physical world.

4. Conduct a test run (All teams)

Using all of the information gathered in steps 1 – 3 above, plan a route for the rover to navigate from the “landing site” to the “sample.” Execute the plan and keep notes on how well the plan works. How far is the planned route? How long does it take to get the rover from the “landing site” to the “sample?”

The team should pick a place to stand outside of the terrain, but close enough so they can see the rover.

- The teams plan a route on the map.
- They put together a series of command sequences that will send the rover on the planned route.
- Blindfold the rover and lead the rover to the “landing site.”
- CAL writes the 1st set of commands on an index card.
- COM delivers the commands as they practiced.
- The rover executes the commands.
- CAL work with MAP to update the rover’s position on the map.
- These steps are repeated until the rover gets to the “sample.”

Instructional objective:

Apply the information gathered in 1 -3 to plan and execute a test run of the rover.

- Analyze multi-step problem solving situations.
- Solve a problem from a visual perspective (using maps and graphs).
- Organize, interpret and use relevant information.
- Communicate conclusions with appropriate mathematical justification.
- Identify alternate ways to find a solution when the original plan fails.
- Develop collaborative team skills.

NCTM Mathematics Standards (K-12 Targets)

18. Problem Solving

b. Solve problems that arise in mathematics and other contexts. Apply and adapt a variety of appropriate strategies to solve problems.

21. Connections

c. Recognize and apply mathematics in contexts outside of mathematics.

Relevance:

NASA tests all equipment before deployment to ensure that the equipment is working properly and to adjust as necessary while still on the ground. It is costly, and sometimes impossible, to repair equipment in space.

Discussion (reserve 10 minutes for this)

- Does the rover get better at remembering commands with practice?
- Does the rover remember some commands or command sequences better than others? What is a reliable number of commands to use to ensure that the rover won't make a mistake?
- Is the shortest distance always the fastest route?
- What features of a map make it easier to use?
- What is the hardest part of getting the rover to go where you want it to go?
- What important reminders should be written down to make sure the run on Mars goes smoothly?

Mars Sample Return (50 minutes)

Now the teams are ready for launch! The objective of this phase is to deploy the rover to Mars to retrieve a sample of the red planet. The teacher should place the sample somewhere on *Mars* where it is visible to the WebCam, after the Mapping Team has completed their map. This activity can be done as a competition among teams.

This activity is the culmination of everything the teams learned in *Arizona*, with two additional complexities: the teams will be viewing their rover from a remote location, and time becomes a critical dimension as the teams attempt to be first to reach the sample.

Note to Teachers without a Web Cam:

PREP for Mars still works fairly well if the students are removed from the direct vicinity of the rover to a location where they can still see the rover. Examples:

- 2-story atrium: rover on ground floor, students above looking down on the rover.
- Room with interior or exterior windows: rover is in one area, students watch through the window.

Instructional objective:

Apply the information learned during the test run in *Arizona* to plan and execute a remote deployment of the rover. Apply what was learned to a more complex problem: the rover is now only visible via the Web cam which introduces issues of perspective and foreshortening.

ITEA Standards for Technological Literacy

Nature of Technology

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

D. A product, system or environment developed for one setting may be applied to another setting.

NCTM Mathematics Standards (K-12 Targets)

18. Problem Solving

b. Solve problems that arise in mathematics and other contexts. Apply and adapt a variety of appropriate strategies to solve problems.

21. Connections

c. Recognize and apply mathematics in contexts outside of mathematics.

Relevance:

NASA deploys remotely operated robots and rovers as part of its missions to explore the Universe and search for life, and inspire the next generation of explorers...

...as only NASA can.

All team members except the rover will be operating from *Mission Control* (a room with a networked that does not have a view of *Mars*). Each team should have its own Mission Control. The Sample Return Mission is broken into 6 phases.

1. Map the *Mars* terrain (Mapping Team)

   The teacher takes to *Mars* to map the terrain to scale using graph paper. The sample is not visible when the mapping is being done. The rover is not permitted to see this map. When MAP return to *Mission Control*, they calibrate the image of Mars they see on the screen (recall, distances will be foreshortened; "Rover left and right" must be related to "Observer left and right" (much like "stage right" and "audience right"). The fiducial marks on the floor or walls will enable the students to calibrate their maps. The students should be told to what actual distance the fiducials correspond.

   During this time the CAL and COM Teams and the rover work on the "Sending Signals to Mars" activity. ? [See Student Activity Sheet for Mars Sample Return Mission.]

2. Launch the rover.

   The teacher takes the rover near *Mars*, but not where the rover can see the terrain. The teacher reminds the rovers again about the rules of the competition (this is the flight time to Mars) while the teams execute the Phase 3.

3. Plan the mission.

   While the rover is enroute to *Mars*, the other team members combine their data to determine the best route and proposed command sequence to get the rover to the sample location.

4. Land the rover on Mars.

   The teacher blindfolds the rovers and places them at their landing sites on *Mars*. We recommend that the landing sites for each rover be well separated and equidistant from the sample.

5. Assemble command sequence (place index cards in proper order).

   COM (now acting as the signal that is sent from *Mission Control*) takes the commands to the rover, and delivers them in the manner that was practiced in *Arizona*. As soon as the commands are successfully delivered, COM returns to *Mission Control*. Recall: COM may deliver the command sequence as many times as is necessary until the rover repeats it correctly. After they say `GOODBYE`, however, they may not communicate again.

6. Execute command sequence.

   The rover executes the command sequence. If the rover makes a mistake, the teacher (or monitor) approaches the rover and says: <rover name> `SHUT DOWN`. The rover responds: <rover name> SHUTTING `DOWN`. The rover then goes into "safe hold" (i.e. does not move) until a new command sequence arrives. NB: *This is why it is so important to calibrate the rover in Arizona. A potential pitfall is that the team gives the rover too many commands to remember and execute correctly.*

Repeat steps 5 & 6 are repeated until the rover retrieves the sample.

Discussion (reserve 15 minutes for this)

- How long does it take a signal to get to Mars? [See Student Activity Sheet for Mars Sample Return Mission.] How long, from the time the signal is sent, must you wait to find out if the rover received your instructions? What part of your activity today simulates the "round trip light travel time?"
- How did viewing the activity via WebCam change the way you had to work?
- What was the hardest part of remote operations?
- What part of your work in *Arizona* did you use during the Sample Return Mission?
- What would you differently next time?
- What tools would make the job easier?

Rules on Mars

Rover is blindfolded.

COM must walk, not run.

COM may repeat the command sequence as many times as necessary until the rover repeats the sequence correctly.

Subsequent command sequences may not be sent from Mission Control until the "active" Communications Team member returns. If this rule is violated, the offending team must wait until the other team has completed a communication sequence before they can go again.

If the rover makes a mistake, the Monitor places the rover into SAFE-HOLD: the rover must stop immediately and wait until the next set of commands are delivered.

If a rover runs into another rover, the Monitor places the rover into SAFE-HOLD: the rover must stop immediately and wait until the next set of commands are delivered. The other rover gets to go first, even if it takes that team longer to get the commands to their rover.

A rover may not move parts of the terrain; it must go around. If a rover runs into a piece of terrain, the Monitor places the rover into SAFE-HOLD: the rover must stop immediately and wait until the next set of commands is delivered.

If a rover is driven out of view of the WebCam, the Monitor returns the rover to the edge of the field of view (facing out) and places the rover into SAFE-HOLD: the rover must stop immediately and wait until the next set of commands are delivered.

The rover that picks up the sample and "lifts arms overhead" is the winner.

Commands

<to be placed on index cards>

Turn (right or left, number of degrees)

Forward (number of steps)

Back (number of steps)

Bend (at waist)

Unbend (at waist)

Extend (right or left) Arm (angle)

Retract (extended arm)

Grasp (with hand)

Lift arms over head

Preparing for the Activity

i. Students' materials

One networked computer (with any web browser) per team (this works best if each team is in a different room; however, they can be in the same room if they are not on top of each other)

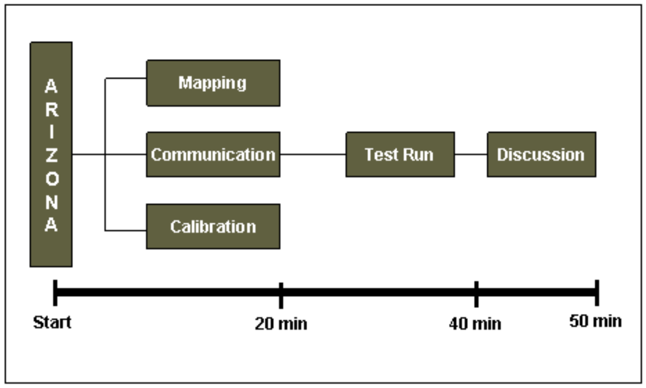
- Large graph paper for mapping landing sites (Each team needs this)
- Ruler for measuring rover's step size (Two per team is helpful)
- Stop watch or watch with digital seconds displayed for timing the rover
- Index cards to write commands on (One pack per team)

ii. Teacher Materials

- WebCam (requires network connection)
  - o See Note on Page 8 if you do not have a Web Cam; you can still do it!
- Mars sample, i.e. the material to be collected by the rover (Mars Bars? ☺)
- It is recommended that there be one monitor for each team (e.g. the teacher, a student aide, a student teacher...basically someone who is not participating in the rover mission). The monitor makes sure the rules are followed an ensures the safety of the blindfolded rover.

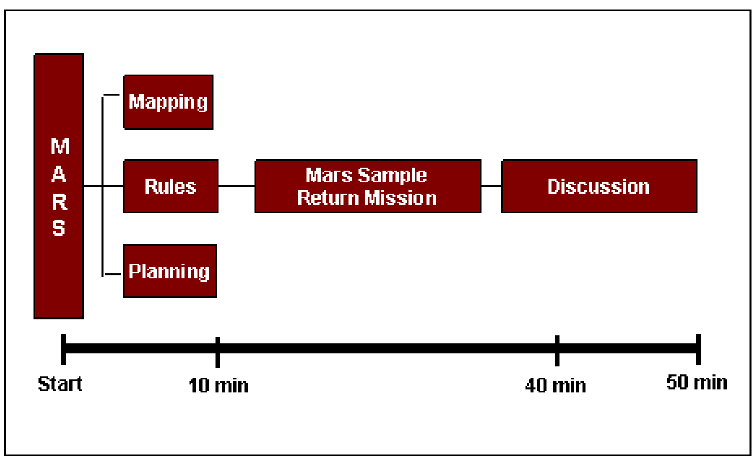
iii. Time (needed for activities)

Not including the time to research the upcoming Mars missions, this activity should take two 50-minute class periods. The first period is for the *Arizona: Calibration of the Rover* phase, and the second period is for the *Mars Sample Return* phase.



***Arizona* Timeline**

In *Arizona*, the Mapping Team, the Communications Team and the Calibration Team are working concurrently to gather data that will be used for planning the Test Run.



***Mars* Timeline**

While the Mapping Team is mapping the *Mars* terrain, the instructor explains the rules of the sample return mission (see **Rules on Mars**, below). As soon as the Mapping Team returns, the group starts planning the rovers path. Ideally, the Mapping Team could get a head-start on their task. Twenty-five minutes are allotted for the Sample Return Mission. The complexity of the terrain is a large factor in determining how long it will take to maneuver the rover to the sample.

iv. Advance Preparation

Background Knowledge (Teacher Preparation)

A basic understanding of graphing data is required. Graphing calculators could help with the visualization of the data. The data in the calibration phase are likely to be roughly linear, thus, an understanding of the equation of a line, slope and intercept are important. A basic understanding of scale mapping is required. The students will need to understand proportions to create scale maps.

Upcoming Missions to Mars (Context)

NASA is planning to send rovers to Mars in 2003 to study the Red Planet. To place the activity in context, background reading on Mars and the missions is recommended. See section on **Web Extensions**.

Arizona: Calibration of the Rover

A sample "terrain" should be set up where the students can calibrate their rover. The teams could either practice in the same "terrain," or they could work in different corners of the room. The "terrain" consists of obstacles around which the rover must maneuver (chairs, tables, etc.) As with the Mars Sample Return phase, it would be beneficial to provide spatial calibration markers (e.g. markings on the floor or the wall) so that the students can draw the "terrain" on graph paper and calibrate the movements of their rover.

Mars Sample Return

An area should be set aside for *Mars*. The same obstacles can be used for Mars as were used for Arizona (or, a creative interdisciplinary twist would be to have an art class design and build different obstacles for Arizona and Mars. How would they differ? How would they be the same?) Since the teams will be in competition in the same area, only one *Mars* is required. We have found it interesting to place the "sample" not quite in the middle of the obstacles, allowing the teams to be creative in their choice of route from the "landing site" to the sample. Keep in mind, however, that your rovers are blindfolded, so you don't want to set up obstacles that are likely to be tripping hazards or otherwise painful to bump into.

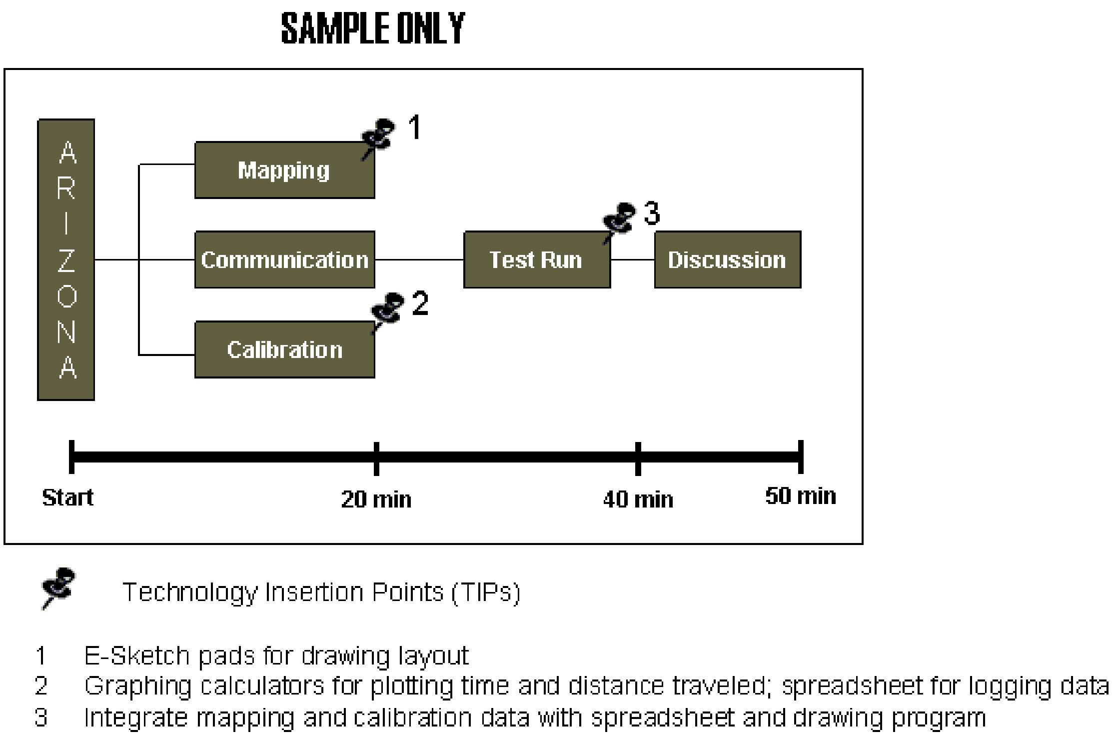
v. Vocabulary

acknowledgment	obstacles	terrain
Arizona	robot	topography
calibration	remote control	WebCam
command sequence	remote sensing	
hand-shaking	rover	
landscape	safe-hold	
launch	scale	
Mars	Solar System	

Technology Insertion Points

The purpose of identifying Technology Insertion Points (TIPs) is to provide flexibility to address varying levels of access to technology in schools.

The TIPs component of *PREP for Mars* is under construction. The figure below is a sample of the type of information we intend to provide.



Resources for obtaining materials

The Axis 2100 Network Camera (WebCam) (www.axis.com) is a high quality, low priced network camera. It can be found searching online for under $300.

Other vendors may have competitive prices; we suggest looking around before buying.

Web Extensions

Destination Mars

www.jsc.nasa.gov/er/seh/destmars.pdf

The lessons are designed to increase students' knowledge, awareness, and curiosity about the process of scientific exploration of Mars. As scientists look for evidence of life on

Mars, they will focus much of their search in areas where volcanic heat and water interacted early in the geologic history of the planet. Two lessons in this packet on volcanoes and mapping river channels reinforce these basic geologic processes. These lessons lead directly to a set of simple activities that help students develop an understanding of the microbial life scientists will be searching for on Mars. The hands-on, interdisciplinary activities reinforce and extend important concepts within existing curricula. Sponsored by NASA's Johnson Space Center and the Houston Museum of Natural Science, Burke Baker Planetarium.

Planetary Society- Mars

www.planetary.org/rrgtm/mars.html

Information on Mars, Mars activities and Mars new from the Planetary Society.

Eventscope

www.eventscope.org

EventScope is a three-dimensional game-like computer interface that allows students to virtually explore remote places like Mars and other planets. Students assume the roles of space scientists in the exploration of these locations from their own classrooms.

ASU/JPL Mars Activities Book

mars.jpl.nasa.gov/classroom/pdfs/MSIP-MarsActivities.pdf

130 pages of Mars related classroom activities and lesson plans developed by Arizona State University and JPL.

JPL's Mars Education Site

mars.jpl.nasa.gov/education/

The Jet Propulsion Lab's Mars education site has links to more resources, news and images of Mars with pages for educators and learners.

National Geographic's Return to Mars

www.nationalgeographic.com/mars/

When it comes to images of distant places, National Geographic is one of the most reliable resources. This is the National Geographic Society's presentation of the first rover mission to Mars.

Ames Mars Atmosphere Modeling Group

humbabe.arc.nasa.gov/MGCM.html

The site has information on Mars and links to images. It provides an interesting comparison between Mars and Earth.

Windows to the Universe: Planetary Systems
www.windows.ucar.edu/tour/link=/our_solar_system/planets.html&edu=elem

Part of the Windows to the Universe site, this website has links to information on all of the planets in our solar system. It includes images, data and resources for parents, teachers and students.

Bridges to other Disciplines

BRIDGES: Language Arts

A Mars theme can be readily introduced into a Language Arts class. Reading and writing, researching and reporting about Mars can be an inspiring set of activities. Whatever course objectives and instructor has, there should be ample material about Mars to meet their needs. Students should benefit from the cross curricular learning opportunity.

Standard 1: Reading

Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

Suggested Readings:

The Martian Chronicles, Ray Bradbury, 1951. (fiction)

Greening of Mars, Michael Allaby and James Lovelock, 1985. (non-fiction)

The Adventures of Sojourner : The Mission to Mars That Thrilled the World, Susi Trautmann Wunsch, 1998. (non-fiction)

Standard 7: Research Papers

Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

Possible Research Topics:

Looking for Life on Mars: The NASA Viking Mission (How did the Viking Mission look for life on Mars? What did they find?)

Compare and contrast Earth and Mars (atmosphere, internal structure, day and night temperatures, size, mass, distance form the Sun, surface features)

Percival Lowell and the Canals on Mars (What did Percival Lowell claim to have discovered? On what did he base these claims? What do we now know about his interpretation of his observations?)

Meteorites from Mars found in Antarctica (What was found? Why do they think the pieces come from Mars? What can be learned from these pieces?)

Martian Moons (Describe the moons of Mars. Compare and contract with the Earth's Moon.)

Standards for the English Language Arts from the National Council of Teachers of English

BRIDGES: History

The history of the space program is a regular part of both United States and World History classes. It is a natural extension of the *PREP for Mars* activity if attention is paid to the history of Mars exploration in addition to the usual coverage of the Apollo Program. It offers the opportunity to put modern exploration into a historical context.

United States History Standards for Grades 5-12

Era 9: Postwar United States (1945 to early 1970s)

Standard 1C

Assess the significance of research and scientific breakthroughs in promoting the U.S. space program.

Era 10: Contemporary United States (1968 to the present)

Standard 2A

Evaluate how scientific advances and technological changes such as robotics and the computer revolution affect the economy and the nature of work.

World History Standards for Grades 5-12

Era 9: The 20th Century Since 1945: Promises and Paradoxes

Standard 2E

Describe worldwide implications of the revolution in nuclear, electronic, and computer technology. [Formulate historical questions]

Suggested outline for a historical study of Mars and Mars exploration

The history of Mars and the interest in Mars.

a. Mars in Myth and Folklore
b. Mars in the Scientific Revolution
c. Canals and Speculation
d. Modern research
    1. Flybys
    2. Orbiters
    3. Landers and Rovers
    4. Current and Planned Missions

All Standards from the National Center for History in Schools

BRIDGES: Visual Arts

Mars as a theme can focus a visual arts class. Interpretation of either research on Mars, preconceptions of Mars or perceptions of the PREP experience would all be valid subjects for visual arts projects. One example or addressing Mars through the arts the *Imagine Mars Project* (imaginemars.jpl.nasa.gov/index1.html), a national arts, sciences and technology education initiative that has harnessed America's fascination with space and led young people to work together with educators and civic leaders to design a Mars community for 100 people.

Content Standard #1: Understanding and applying media, techniques, and processes

- Students select media, techniques, and processes; analyze what makes them effective or not effective in communicating ideas; and reflect upon the effectiveness of their choices
- Students intentionally take advantage of the qualities and characteristics of art media, techniques, and processes to enhance communication of their experiences and ideas

Content Standard #2: Using knowledge of structures and functions

- Students generalize about the effects of visual structures and functions and reflect upon these effects in their own work
- Students employ organizational structures and analyze what makes them effective or not effective in the communication of ideas
- Students select and use the qualities of structures and functions of art to improve communication of their ideas

Content Standard #3: Choosing and evaluating a range of subject matter, symbols, and ideas

- Students integrate visual, spatial, and temporal concepts with content to communicate intended meaning in their artworks
- Students use subjects

Content Standard #6: Making connections between visual arts and other disciplines

- Students compare the characteristics of works in two or more art forms that share similar subject matter, historical periods, or cultural context
- Students describe ways in which the principles and subject matter of other disciplines taught in the school are interrelated with the visual arts

Standards from the National Standards for Arts Education developed by the Consortium of National Arts Education Associations.

Potential Follow-on Activities

Botball

www.botball.org

The Botball Educational Robotics Program is a hands-on learning in science, technology, engineering and math program. It is designed for middle and high school students, and offers a national collegiate competition. Students gain experience and design, build and program their own robots.

FIRST Robotics

www.usfirst.org/robotics/

The FIRST Robotics Competition is an exciting, multinational competition that teams professionals and young people to solve an engineering design problem in an intense and competitive way. In 2003 the competition will reach more than 20,000 students on over 800 teams in 24 competitions. The teams come from Canada, Brazil, the U.K., and almost every U.S. state. The competitions are high-tech spectator sporting events, the result of focused brainstorming, real-world teamwork, dedicated mentoring, project timelines, and deadlines.

Mars Student Imaging Project

msip.asu.edu/home.php

NASA and Arizona State University's Mars Education Program is offering students nationwide the opportunity to be involved in authentic Mars research by participating in the Mars Student Imaging Project (MSIP). Teams of students in grades 5 through college sophomore level will have the opportunity to work with scientists, mission planners and educators on the THEMIS team at ASU's Mars Space Flight Facility, to image a site on Mars using the THEMIS visible wavelength camera onboard the *Mars Odyssey* spacecraft which is currently orbiting Mars every 2 hours.

NASA Student Involvement Program

www.nsip.net/about/index.cfm

The NASA Student Involvement Program (NSIP) is a national program of six competitions for grades K-12 that link students directly with NASA's exciting missions of exploration and discovery. Each NSIP competition category has a Resource Guide that provides instructional materials, judging rubric, tips, and resources for using investigations and design challenges in your classroom. These materials support national standards, state frameworks, and local school curricula.

NSIP sponsors the Design a mission to Mars and Beyond as an educational activity and a competition. It is a good complement and extension to *PREP for Mars*.

See www.nsip.net/competitions/mission/index.cfm

NASA's Student Jobs site

www.nasajobs.nasa.gov/stud_opps/

Opportunities for student jobs are announced on this site, as NASA seeks to enhance its diverse, highly-qualified workforce. NASA continues to develop revolutionary technologies that are helping to improve aviation safety and efficiency, probe deeper into the mysteries of the universe, propel robotic emissaries more swiftly through the solar system, and work to better understand the dynamics of the Earth's climatic system.

Appendix A: Assessment

Assessment is a vital part of modern education. It is necessary for educators to be able to gain insight into the learning of their students.

Embedded Assessment

Embedded assessment differs from outcomes assessment in that it occurs throughout a unit in order to chart progress, rather than at the end of a unit to measure the level to which objectives have been mastered. This is also referred to as formative assessment, performance and alternative assessment. (*Teaching Today*)

PREP

Assessment is inherently a teacher's choice. PREP does not dictate any particular form of assessment but it has been consciously designed to support embedded assessment. PREP is designed to allow teachers to assess learners' mastery of skills by observing skills in use.

Authentic Assessment

Authentic assessment refers to assessing authentic activities and work. In opposition to traditional assignments designed simply to demonstrate or showcase an idea or principle, authentic assignments simulate real world activities. While it is conceivable that one train leaves Chicago at the same time another leaves Philadelphia and they are headed towards each other, the time they intersect is of no real importance to anyone unless they happened to be the rare traveler who forgot vital papers in their starting city. Such artificially concocted word problems are and example of the kinds of unrealistic problem tasks that result when relevance to the real world is not a consideration.

PREP

PREP is based on remote exploration. It simulates a sample return mission. It exposes learners to the principles of remote exploration and interplanetary communication. Most of the challenges the teams face are very much the same challenges that a real Mars rover mission team faces. Most importantly it takes learners into the role of NASA mission scientists and engineers. That inspires the learners to see that they can be the next generation of explorers.

Summative Assessment

Summative assessment often comes after the activity is complete. It is often referred to as a standard or traditional assessment. While traditional and standard assessment generally entail some sort of written or oral test to gauge learner understanding, judging the outcome or product of an activity also falls within the realm of summative assessment. More commonly, however, summative assessment takes the form of a test (written, oral or computer-based) or a presentation or report.

PREP

The most natural summative assessment of PREP would be the mission outcome. In its simplest form, success or failure would dictate the assessment, but as in real life, there is much to be learned even from a failed mission in PREP. A teacher could ask for a report about the activity or test with a traditional instrument. If a general test is given instead of a group report or test, a teacher must make sure that all students have had a chance to be on each sub-team. It would be particularly unfair to test the rovers on mapping concepts, for instance, if the only part they ever played was as the rover. The discussion questions provided in PREP could be used as the foundation for a summative assessment tool.

Teaching Today is a Web site from the Glencoe/ McGraw-Hill Secondary division. Published by Glencoe/McGraw-Hill, a division of the Educational and Professional Publishing Group of The McGraw-Hill Companies, Inc.,

Appendix B: *PREP for Mars* and the Learning Cycle

The learning cycle is an instructional strategy and filter that guides lesson design and selection. It is fundamentally based in the Constructivist philosophy that students learn best when actively engaged in learning activities. *PREP for Mars* displays the spirit of the learning cycle in its imagination firing, hands-on, immersive structure.

Whatever the subject or grade level, the learning cycle offers a proven instructional strategy for engaging middle school students. It helps them see the relevance of learning, and makes learning more interesting and enjoyable. Encouraging teachers to incorporate the learning cycle into their teaching repertoires is certainly a promising step toward helping middle-level students become active participants in their own learning.

Research shows that learning is based on motivation, active involvement in the learning process, linking new concepts with familiar information, and applying new information to the real world (Silver, 1998). Proponents of the learning cycle strategy believe it can be used for every subject and at every grade level to meet the needs of diverse learners. Students seem to experience more success and develop greater thinking skills as they share responsibility for their learning.

The Five Es are a construct of the Biological Science Curriculum Study (BSCS) led by Roger Bybee (2002). They are a convenient filter for breaking learning in constituent parts to allow a more comprehensive approach to addressing active learning.

Briefly, this learning approach can be summarized as follows: Learning something new, or attempting to understand something unfamiliar, is not a linear process. In trying to make sense of things learners use both their prior experience and the first-hand knowledge gained from new explorations. In the best cases learners, like scientists, can be enticed to poke and prod and inquire about a new situation or idea until they develop understanding. As they begin to investigate new ideas they can put together bits and pieces of prior explorations that seem to fit their understanding of the phenomena under investigation. Sometimes when the pieces do not fit together, they must break down old ideas and reconstruct them. Learners extend their conceptual understanding through discussions and creative efforts. Learners validate their theories as they solve problems.

Engage

In the stage Engage, the students first encounter and identify the instructional task. Here they make connections between past and present learning experiences, lay the organizational ground work for the activities ahead and stimulate their involvement in the anticipation of these activities. Asking a question, defining a problem, showing a surprising event and acting out a problematic situation are all ways to engage the students and focus them on the instructional tasks. If we were to make an analogy to the world of marketing a product, at first we need to grab the customer's attention. We won't have their attention unless they have a need to buy the product. They may be unaware of a need, and in this case we are motivated to create a need.

PREP

PREP for Mars is designed to be an engaging activity. To make the most of the learning cycle, a good activity has to capture the interest of students from the start. NASA has the power to inspire the imagination students, and *PREP for Mars* uses that power to draw out their interest. With motivation fueled by NASA and Mars students participate enthusiastically in *PREP for Mars.* A key premise of Constructivism is that students learn best through active and enthusiastic participation. In this way, *PREP for Mars* engages the interest and imagination of students as only NASA can.

Explore

In the Exploration stage the students have the opportunity to get directly involved with phenomena and materials. Involving themselves in these activities they develop a grounding of experience with the phenomenon. As they work together in teams, students build a base of common experience which assists them in the process of sharing and communicating. The teacher acts as a facilitator, providing materials and guiding the students' focus. The students' inquiry process drives the instruction during an exploration.

PREP

With a name like Principles of Remote Exploration, it is important to distinguish the explore in the learning cycle from the exploration in *PREP*. "Explore" as used in the learning cycle covers all manner of active inquiry. *PREP* is an exploration based activity both figuratively and literally. In the learning cycle sense, it is an activity that invites students to be actively engaged in problem solving. It is up to the students to work out solutions to the challenges of guiding their rover remotely. It is up to the students to develop good lines of communication between the sub-teams. *PREP* builds in very specific challenges like delayed communication time and physical obstacles. They are there for the purpose of pushing the student teams to develop their own approaches to deal with challenges. Given sufficient time to do the activity, the student can experiment with different approaches. It is not the fact that PREP is a simulated exploration that makes it an exploration activity in the learning cycle sense. It is the fact that is an inquiry based activity that gives students the chance to be actively involved in the problem solving process.

Explain

Explain is the point at which the learner begins to put the abstract experience through which she/he has gone into a communicable form. Language provides motivation for sequencing events into a logical format. Communication occurs between peers, the facilitator, or within the learner himself. Working in groups, learners support each other's understanding as they articulate their observations, ideas, questions and hypotheses. Language provides a tool of communicable labels. These labels, applied to elements of abstract exploration, give the learner a means of sharing these explorations. Explanations from the facilitator can provide names that correspond to historical and standard language for student findings and events. For example a child, through her exploration, may state that she has noticed that a magnet has a tendency to "stick" to a certain metallic object. The facilitator, in her discussion with the child, might at this stage introduce terminology referring to "an attracting force". Introducing labels, after the child has had a direct experience, is far more meaningful than before that experience. The experiential base she has built offers the student an attachment place for the label. Common language enhances the sharing and communication between facilitator and students. The facilitator can determine levels of understanding and possible misconceptions. Created works such as writing, drawing, video, or tape recordings are communications that provide recorded evidence of the learner's development, progress and growth.

PREP

While *PREP for Mars* provides a rich environment with a high density of learning opportunities, if there is no time for reflective discussion and thought, much of the potential will not be realized. Students should be able to explain why some approaches were more successful than others. They should be able to reflect on both their successes and difficulties to garner greater insight. Because of the exploratory and team nature of *PREP for Mars*, there should be sufficient examples to compare approaches and grasp the principles behind successful strategies. This reflective time provides a chance both for the teacher to introduce formal terms and names of concepts and for students to explain in their own words. It also provides and opportunity for student discourse to uncover deeper levels of understanding in a personal and meaningful way. Each section of *PREP* ends with discussion questions to promote reflection.

Extend

Elaborate, the students expand on the concepts they have learned, make connections to other related concepts, and apply their understandings to the world around them. For example, while exploring light phenomena, a learner constructs an understanding of the path light travels through space. Examining a lamp post, she may notice that the shadow of the post changes its location as the day grows later. This observation can lead to further inquiry as to possible connections between the shadow's changing location and the changes in direction of the light source, the Sun. Applications to real world events, such as where to plant flowers so that they receive sunlight most of the day, or how to prop up a beach umbrella for shade from the Sun, are both extensions and applications of the concept that light travels in a straight path. These connections often lead to further inquiry and new understandings

PREP

Arizona is the place to gain understanding of how the rover works and to calibrate the rover's movements. Students carry over what they have learned working with the rover in *Arizona* and apply it to their sample return mission to *Mars*. Once the rover is on *Mars*, failure of the *mission control* to have adequately acquainted themselves with the operations of the rover can be a serious handicap. A *mission control* that does not know the length of steps or turning angles of their rover will have a very difficult time guiding the rover on *Mars*. Such difficulties create a learning opportunity to grasp the importance of calibration. Success can also teach the same lesson, though it may not be as readily apparent without difficulties with which to compare the success. If students have the time to run the mission multiple times, they can demonstrate increased understanding of the principles required for success and in doing so improve their retention of the lessons learned.

Evaluate

Evaluation should be an on-going diagnostic process that allows the teacher to determine if the learner has attained understanding of concepts and knowledge. Evaluation and assessment can occur at any points along the continuum of the instructional process. Some of the tools that assist in this diagnostic process are: rubrics (quantified and prioritized outcome expectations) determined hand-in-hand with the lesson design, teacher observation structured by checklists, student interviews, portfolios designed with specific purposes, project and problem-based learning products, and embedded assessments. Concrete evidence of the learning process is most valuable in communications between students, teachers, parents and administrators. Displays of attainment and progress enhance understanding for all parties involved in the educational process, and can become jumping off points for further enrichment of the students' education. These evidences of learning serve to guide the teacher in further lesson planning and may signal the need for modification and change of direction. For example, if a teacher perceives clear evidence of misconception, then he/she can revisit the concept to enhance clearer understanding. If the students show profound interest in a branching direction of inquiry, the teacher can consider refocusing the investigation to take advantage of this high level of interest.

PREP

From a performance-based assessment perspective, *PREP for Mars* is a self-evaluating exercise. Because the object is to complete a simulated sample return mission, completing the mission is the measure of success. The depth of student understanding of the principles behind the activity can be gauged through questioning and discussion. Students should be able to explain why some efforts were more successful than others. Students should be able to both ask and answer hypothetical questions about how the mission would change if other factors where introduced. With true understanding, students should have a model in their minds that they are able to manipulate and reason with using examples and evidence. Students should be able to make sense of teachers' formal explanations of principles related to remote exploration.

Different teaching styles will dictate how the teacher determines and rates the students' knowledge. Some teachers will prefer a written quiz or oral examination to assess learning. Some teachers will be content with the sense they garner of understanding from student interaction. Some teachers will ask students to write an explanation directly or a story to indirectly demonstrate their understanding.

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